Active Project (2014 - 2017)

Computational Model for Spacecraft/Habitat Volume Project

Human Exploration And Operations Mission Directorate (HEOMD)

ABSTRACT

A key design challenge for future long-duration exploration missions is determining the appropriate volume of a spacecraft/habitat to accommodate habitability functions and ensure optimal crew health, performance and safety. Because spacecraft/habitat volume directly drives mass and cost, this information is needed early in the design process. This proposal is in response to the NASA Research Announcement (NRA) NNJ13ZSA002N A.2.i: Computational Modeling and Simulation for Habitat/Vehicle Design and Assessment, and it addresses the Human Research Program (HRP) Program Requirements Document (PRD) Risk of Incompatible Vehicle/Habitat Design. The objective of this proposal is to develop a constraint-driven, optimization-based model that can be used to estimate and evaluate spacecraft/habitat volume. The computational model development will be completed through four Specific Aims: Estimate spacecraft/habitat volume based on mission parameters and constraints, provide layout assumptions for a given volume, assess volumes based on a set of performance metrics, and inform risk characteristics associated with a volume. To accomplish this, the proposed team has been structured to leverage expertise from diverse fields, including architecture and habitation design, human factors engineering, industrial engineering, optimization-based modeling, and simulation. The proposed work will also leverage technical products developed from the HRP-hosted 2012 Habitable Volume Workshop, as well as work performed in the follow-on exploratory project in 2013, including critical task volume estimations and input/output definitions for the computational model. Lessons learned from the development of the Integrated Medical Model (IMM) developed by the Exploration Medical Capability Element (ExMC) of the HRP will also be applied to the proposed work - lessons ranging from model development approach to compliance with NASA STD 7009, Standard for Models and Simulation. Model validation and verification will be a continuous process occurring throughout model development.

Human Research Program Image

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The guidelines of NASA-STD-7009 will be followed in establishing parameters and vetting the credibility of the model at all stages of development. The outcome of the proposed work will directly answer to HRP's Risk of Incompatible Vehicle/Habitat Design and the associated SHFE-HAB-09 Gap on technologies, tools, and methods for data collection, modeling, and analysis for design and assessment of vehicles/habitats. A computational model for spacecraft/habitat volume will be an invaluable tool for designers, mission planners, integrators and evaluators who are shaping space habitats and working toward a truly habitable environment for future long-duration exploration missions.

ANTICIPATED BENEFITS

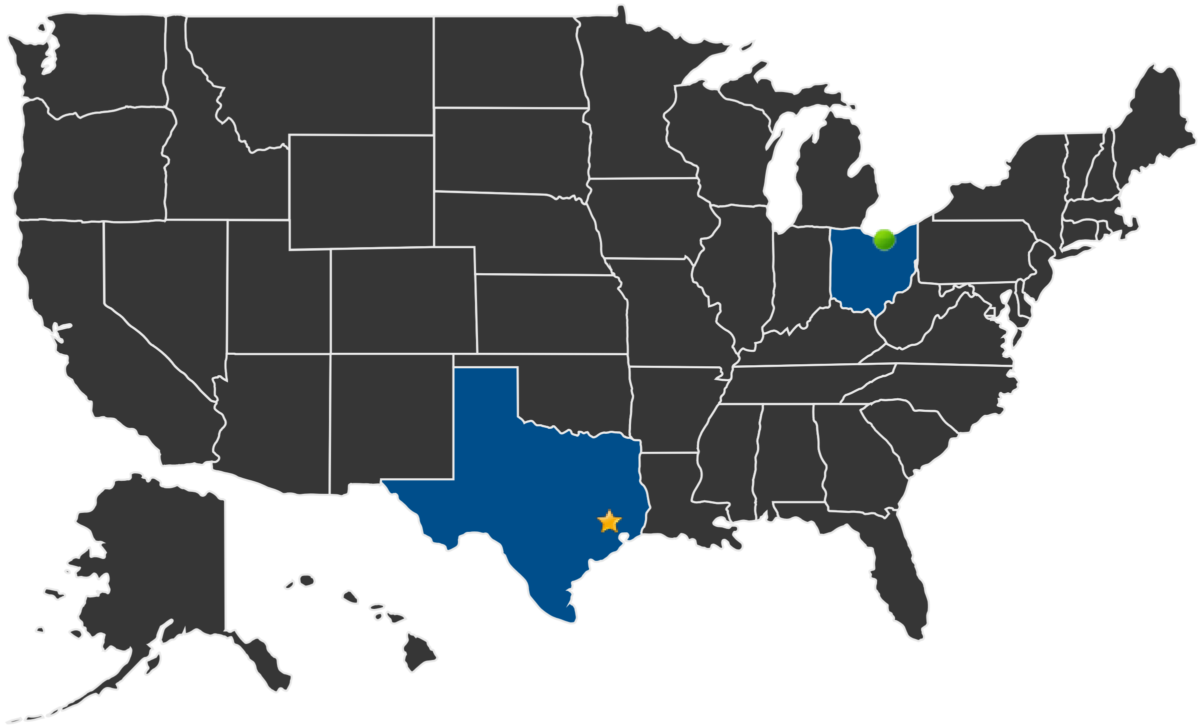
To the nation:

Earth industries that are concerned with habitability in confined environments for long durations (e.g., shipping, submarines, oil and gas rigs, Antarctic research stations) may benefit from the task-based approach in development for determining overall volume needs.

DETAILED DESCRIPTION

Work during Year 1 of this study has included selecting a software platform; developing model requirements; defining model inputs, outputs, and constraints; developing strategies for optimization approaches; and beginning work on verification and validation plans. To select the best software platform for the Spacecraft Optimization Layout and Volume (SOLV) model, the team completed a trade study of software programs including SAS, SPSS, Mathematica, MATLAB, and R. Considerations such as optimization and statistical capabilities, price, user interface, and validity concerns were rated. Based on the project needs, the team determined that an appropriate strategy will be to use MATLAB as the primary software platform, and SAS as needed only in prototype model development. Model development began with defining requirements for model functionalities and implementations. A list of high-level requirements has been compiled, including key driving requirements (KDRs) that specify the overarching architectural concepts; model variables, inputs and outputs; user interfaces; and processes by which the model code can be verified, shared, and utilized. The KDRs were peer-reviewed and concurred at the team midterm review on 2/13/15. Forward work includes further refinement of requirement verbiage and the specification document, in addition to the development of planned verifications for each KDR. One of the major goals this year has been the building of a “toy problem” consisting of a limited set of critical inputs. The toy problem will enable the team to identify and analyze all of the variables and experiment with different architectural concepts. The initial strategy for the toy problem used a 3D “bin packing” or the “Knapsack” method often employed by the airline industry to optimize cargo loading. The decision was made to move the model architecture away from a deterministic, geometry-based optimization into a multivariate, probabilistic computation. To support the new architecture, the team worked to define model inputs, outputs, constraints, and modeling logic that governs the manner in which constraints would be applied. For inputs and outputs, Excel spreadsheets were used to visually represent the types and levels of inputs the users are expected to enter into the computational model, and the types of outputs or data products the model is expected to produce. Types of model inputs include critical task volumes, mission duration, number of crew, and space typology. Types of model outputs include total optimized volumes, configuration layout options, input summary, scorecard- or stoplight-type assessments based on mission, performance, and human health metrics. A constraint-driven model framework seeks to optimize its objective functions with respect to the variables in the presence of constraints on those variables. Two primary objective functions are defined for the model: • Minimize overall aggregate of task volumes • Minimize overall costs associated with merging the task volumes. An Excel spreadsheet was used to capture the types of constraints, including task attributes that impact how task volumes overlap to minimize the overall volume, such as task time, concurrency, and geometries; and constraints that govern the spatial relationships among task volumes (i.e., to what extent a task should be separate from another task), such as environmental constraints and functional adjacencies. Optimization is a two-step process that first starts with the relative layout of the tasks based on environmental zoning and functional adjacencies and is followed by the packing or merging of task volumes in accordance with task attributes. A Chow-Liu tree/Bayesian network will be set up to define the level of information (and by extension, the level of uncertainty) between any pair of constraints in order to prioritize the constraint application in the model and drive model logic. Rigorous verification and validation as well as uncertainty quantification are essential for interpreting the relevance of predictions derived from a given model. To ensure breadth and quality of verification and validation, codes will be tested against examples from the literature and known engineering “best practices,” as well as against the most current data that NASA can provide, including Subject Matter Expert feedback. The guidelines of NASA-STD-7009 will be followed in establishing parameters and vetting the credibility of the model at all stages of development. Thus, model validation and verification will be a continuous process occurring throughout model development, and progressing through incremental testing of functionality starting at the subcomponent level. Validation data will be obtained from ground-based test and analysis, including human subject data collection in a vehicle mockup setting. Tools developed for automated collection of data including space utilization, crew activity, and vehicle habitability can potentially be used as part of this process. The V&V plan will also outline continued validation efforts which may eventually utilize resources such as Johnson Space Center’s Human Exploration Research Analog (HERA), other ground-based analogs, or flight tests including parabolic flights.

U.S. WORK LOCATIONS AND KEY PARTNERS



U.S. States With Work

Lead Center:
Johnson Space Center

Supporting Centers:

- Glenn Research Center

Other Organizations Performing Work:

- Lockheed Martin Space Systems Company
- Texas Tech University